INTEGRATED GEOTHERMAL WELL TESTING: TEST OBJECTIVES AND FACILITIES

R. W. Nicholson
Well Production Testing

O. J. Vetter
Vetter Research

United States

ABSTRACT

A new and highly integrated geothermal well test program was designed for three geothermal operators in the United States (MCR, RGI and Mapco Geothermal). This program required the design, construction and operation of new well test facilities.

The main objectives of the test program and facilities are to investigate the critical potential and worst problems associated with the well and produced fluids in a period of approximately 30 days. Field and laboratory investigations are required to determine and quantify the problems of fluid production, utilization and reinjection.

The facilities are designed to handle a flow rate from a geothermal well of one million pounds per hour at a wellhead temperature of approximately 268°C (515°F). The facilities will handle an entire spectrum of temperature and rate conditions up to these limits. All pertinent conditions for future fluid exploitations can be duplicated with these facilities, thus providing critical information at the very early stages of field development.

The new well test facilities have been used to test high temperature, liquid-dominated geothermal wells in the Imperial Valley of California. The test facilities still have some problems which should be solvable. The accomplishments of this new and highly integrated geothermal well test program are described in this paper.

DISCLAIMER

INTRODUCTION

Geothermal well testing involves both the confirmation of conventional reservoir parameters as well as the determinination of all aspects of brine production, handling, utilization and reinjection. Testing of geothermal wells is quite different from the testing of oil and gas wells. The objectives, test procedures and equipment differ drastically. The early geothermal industry in the USA has not understood these differences. Thus, inadequate planning and execution of geothermal well testing have had four negative impacts:

1. Potentially good wells were damaged or even lost during improper testing.

2. "Piecemeal" testing, as commonly done, became prohibitively time-consuming and expensive.

3. Gathering of wrong or false data has lead to interim and costly misconceptions, thus causing undue costs and delays.

4. Collecting of inadequate data caused major problems in financing geothermal projects.

Inadequate well and reservoir evaluations through improper testing have substantially contributed to the languishing development of the geothermal industry within the United States.

In this paper we describe briefly the earlier tests in the North Brawley and East Mesa KGRA's (Known Geothermal Reservoir Area) in which one or both of the authors have participated. Based on these earlie experiences a new well testing program has been developed for three major geothermal developers in the USA. This new program required the construction of rather complex and portable test facilities to be used in various locations. These facilities are designed to handle any type of geothermal brine. The test program and facility allow the simultaneous testing for the critical parameters and systems related to the: (1) reservoir, (2) wellbore and production, (3) brine utilization, (4) reinjection, and (5) environment.

The two main goals for the new geothermal well testing were to design:

a) A portable and self-contained well test unit, and

b) A thoroughly integrated well test program.

The test unit and test program allow the critical data about a geothermal well to be measured in a relatively short period of only thirty (30) days. This is quite an accomplishment compared to earlier attempts at geothermal well testing in the Imperial Valley and various other areas in the United States.

The portable geothermal test unit was constructed to fulfill the requirements for integrated geothermal well testing [1] and is described in this paper. The basic unit as originally designed and built has undergone quite a few modifications to handle problems encountered during actual well tests at the sites of RGI's Well Fee 1, Mapco's well Currier 2 and MCR's well Mercer 2 sites. The test unit will undergo future modifications to enable testing at other sites. These modifications will continue to be required so as to handle each set of unique problems encountered at various geothermal test sites.

A pit-test using major parts of the test unit at RGI's Fee site and a thirty (30) day test using the entire test facility at Mapco's Currier 2 well [2] were successfully conducted. At the writing of this paper the second thirty (30) day test is being conducted at MCR's Mercer 2 well in Imperial, California. Basically, the test unit has performed according to specifications. Site specific problems, such as production of large amounts of sand at the Currier site and the formation of rather exotic scales at the Mercer site did create some problems.

The test unit has allowed production testing with concurrent low temperature reinjection. This has allowed the collection of all physical and chemical data necessary for complete preliminary evaluations leading to a final power plant design. Problems encountered during testing with initial oxygen corrosion and related injectivity problems [3] were initially overcome by acidizing and then later by hydrazine additions. A crystal clear brine ready for reinjection was produced after successful flocculation experiments with a single compound flocculant.

PROBLEMS RELATED TO TYPES OF WELLS

To design generally applicable geothermal well test facilities and test programs is nearly an impossible task. As outlined below, different reservoir temperatures and brine compositions can lead to very site-specific problems. In addition, the short and long-term plans of any operator may require special test equipment and procedures at any given site. For example, an operator of a low temperature/low TDS (Total Dissolved Solids) brine reservoir may want to pursue the exploitation of this reservoir through a binary electric power plant or through direct heat utilization, whereas another operator (high temperature/high TDS brine) may be interested in a multiflash cycle power plant combined with a gasohol plant and/or a mineral recovery process. It becomes rather obvious that the different operators have quite different test goals regarding their particular site-specific plan for future field developments.

Nonetheless, we believe that our test facilities and test programs are adaptable for all site-specific test work. The test unit was designed with the largest degree of flexibility economically possible. Some unit components which may be unnecessary for a given test and can easily be deleted or by-passed. Some tests will require unit components which may have to be designed and added. Again, this can be accomplished with minimum technical and economic efforts due to the applied "building block" system. The test unit as described in this paper can provide the back-bone for any geothermal test work in any field by making only minor adaptations.

Below, we will briefly outline some of the major differences in various test programs dictated by site-specific geothermal reservoirs. Basically, present KGRA's in the United States produce from (1) low and moderate temperature wells and (2) high temperature wells. Also, the fluids produced can have either (1) a low TDS or (2) a high TDS content. Both temperature and chemical composition of a given brine are critical for any test program.

Two of the major problems during the development of a geothermal prospect are caused by:

1. Scale problems and
2. Reinjection problems due to suspended particles.

Even though it is generally recognized that both scale and reinjection problems are related to the reservoir brine temperatures and composition, there exist still critical misconceptions within the geothermal industry. A low TDS/low or high temperature brine is considered "better" and easier to handle than a high TDS/high temperature brine as far as scale formation is concerned. This is a definite misconception as demonstrated by the wells in Roosevelt Hot Springs, Bacca, Westmorland and East Mesa. These wells produce low TDS brines and can still pose severe downhole scale problems. As a matter of fact, the downhole $CaCO_3$ scale in many low TDS wells can be extremely difficult and costly to fight. High temperature/high TDS brines, on the other hand, are not only more valuable but the scale can be handled in a simpler and more economical way [2,3]. Most of these high temperature/high TDS brines form scale in the surface equipment where it is easily accessible and removable or where other counter measures can be taken.

The suspended solids causing the majority of the reinjection problems are mainly generated by silica precipitations [1,2,3]. These silica precipitations are normally the more severe the higher the reservoir temperature. This means the silica preciptations are more or less independent of the brine composition. The TDS content of the brine has only minor effects on the silica preciptations. Temperature is the critical factor.

Considering these basic conditions, the test unit was designed to handle high and low temperature brines as well as high and low TDS fluids. This was accomplished not only by proper pressure and temperature ratings of the pressurized portions of the described test unit but also by the careful sizing of each component of the entire test facility. The test program itself can easily be adapted to the various site-specific temperature and TDS conditions, thus allowing an elaborate and thorough evaluation of all major scale and reinjection problems expected during the future development of any given field.

RECENT EXPERIENCES WITH GEOTHERMAL WELL TESTING

Below, we not only describe the geothermal well test facilities, its present design, and operational conditions. In addition, some of our field experiences using these facilities at a number of wells are described.

4.1 DESIGN OF THE TEST FACILITIES

The test unit facilities are designed to accomplish two primary objectives. The first objective is to flow test a production well for an extended period of time with concurrent low temperature reinjection of the heat-depleted brine. The second and most important objective is to support the collection of flow data and fluid data under a variety of flow conditions. The further development of a field after testing a well will greatly depend upon the physical and chemical data collected during this well test.

DESIGN CRITERIA IN GENERAL

The design parameters (pressure, temperature and flow capacity) are determined by the wellhead fluid specifications and also by required data, i.e., the data desired for analyses of the reservoir and the fluids. Reservoir evaluations can be made under a variety of flow conditions if the bottom hole pressures and temperatures at each flow condition are known. However, the fluids must also be studied under a variety of conditions other than the bottom hole flow conditions.

The upper limits for the conditions (pressures, temperatures and rates) of the high and low pressure systems are given in Table 1. The test unit can be operated under many complex combinations of conditions up to the maximum conditions of each system. In addition, lower wellhead pressures and temperatures can expand these maximum system operating limits. However, the operating pressure must be maintained below the design working pressure of the various system components.

The facilities consists of several groups of components as schematically shown in Figure 1. This shows an extremely simplified version of the present complex facility shown in Figure 2. Even this version shown in Figure 2 has been recently modified to handle unusual scaling conditions encountered during the MCR Mercer 2 test. This addition involves a sacrificial spool for scale removal and has been added to the system as shown in Figure 3. This sacrificial spool is nothing else but a convenient location to drop the scale instead of allowing it to form throughout the test facility. Another benefit of this sacrificial loop is the gathering of additional data for mineral recovery.

DESIGN CRITERIA FOR SPECIFIC UNIT MODULES

There are three main groups of components of the geothermal well test facility. These are (1) the pressure system, (2) the atmospheric system, and (3) the reinjection system. Each of these systems are designed to be compatible with the other components in the system. Within and between the unit modules, maximum flexibility is designed into the system to handle almost any unanticipated operational problems.

PRESSURE SYSTEM

The pressure system consists of separators, test loops, sacrifical loops, valves and piping necessary to evaluate the reservoir fluids under a variety of flow conditions. The pressure system is further divided into the high pressure and low pressure system. The high pressure system consist of 10 inch piping and valves (600 lb. rated ANSI) to handle well head pressures and temperatures as shown in Table 1. The low pressure system consists of 10 inch piping and valves rated to 150 lb. rated ANSI.

There are two test loops and one sacrificial loop in the system. The high pressure loop is located upstream of the high pressure separator. The low pressure loop is downstream of the high pressure separator. The loops are operated by by-passing the entire flow stream through the loop and deliberately creating pressure/temperature drops through orifice plates. Thus, the thermodynamic stability of the fluid can be studied under a variety of temperature and pressure conditions in a short period of time. The sacrificial loop consists of 30" piping with various types and numbers of inserts. This sacrifical loop can replace the low pressure test loop in the system and will allow scale formation in a preferred and accessible location. The scale in this loop will not interrupt the long-term production testing.

The brine and steam outlets from both the low and high pressure systems are designed to allow rate measurements with several devices. The separators have been operated under a variety of conditions and allowed reasonable separation for accurate fluid chemistry and flow data.

The separators must handle low flow rates as well as high flow rates. The separators are designed primarily for high flow rates. However, the separators are also capable of separation at low flow rates. Thus, vertical separators are used where the fluid at high flow rates is accelerated around the inner wall of the separator to expose a large area of the fluid in a thin sheath allowing the steam to readily escape. The high velocity around the walls of the separator helps to keep scale from adhering on the separator walls. At low flow rates the vessels act as a flash chamber since at low rates minimal tangential flow around the inside of the separator can occur. The separation efficiency is in excess of 99.9% under most operating conditions.

ATMOSPHERIC SYSTEM

In contrast to the pressure system described above, the atmospheric system of the test facility has a dual purpose:

1. It must allow the various requirements of the overall test program at atmospheric pressures to be achieved. We do not believe that high pressure/high temperature reinjection of brine as presently pursued by Union Geothermal will lead to a long-term solution of reinjection problems. Only low pressure/low temperature brine reinjection will lead to technically and economically feasible solutions of these reinjection problems. To provide these solutions, the well test program under atmospheric conditions becomes a very critical part of the overall well test program.

2. During the actual well test work, the heat-depleated brine must be reinjected without unduely endangering the injectivity of the injection well. This generates the problem that the brine must be rendered reinjectible prior to performing the test work for proper reinjection. Ironically, the test data must be applied before they are obtained. This is the most difficult part of any test program.

Therefore, the atmospheric system as described below not only provides valuable information for future field developments but must also be flexible and efficient enough for a temporary treatment of the heat-depleted brine to allow reinjection during the field tests.

The atmospheric system consists

of several groups of equipment for rendering the heat depleted brine reinjectible. These basic groups of equipment are: (1) the reactor, (2) the fluidized beds, (3) the settling system, and (4) the filter system. The entire system is designed for 1000 gpm of brine.

REACTOR-CLARIFICATION

Reactor-clarification seems to be a viable way to render the heat-depleted brine reinjectible. The major problem is the proper design of the reactor-clarification system particularly, its sizing. Therefore, reactor-clarification experiments play an important role during our field test work.

In order to obtain the necessary data for future reactor-clarifier designs, we split the conventional reactor-clarifier into its three basic parts:

1. Reactor ("draft tube" or nucleation section)

2. Fluidized bed (particle growth section)

3. Settling bed (clarification section)

This physical separation of a conventional reactor-clarifier into its three basic components not only facilitates a convenient collection of critical brine data, while allowing us to make the entire unit portable.

THE REACTOR

The reactor vessel (see Figure 4) has three functions. First, the brine from the low pressure separator is flashed to atmosphere in the reactor. Thus, it acts as an atmospheric flash chamber. Second, it acts as a low noise steam stack since the steam from both the low pressure separator and the high pressure separator are discharged to the atmosphere through the upper portion of the reactor. Third, and most importantly, the reactor is the first stage of the brine clarification system. The brine within the reactor is circulated with a high volume pump at 10,000 gpm. This creates many particles collisions and initiates the crystallizaton process (seeding). Thus, many particles are formed which provide the surface area for subsequent precipitation. Therefore, the precipitating material grow on the suspended particles instead of on the walls of the equipment (scale).

FLUIDIZED BED

From the reactor vessel the brine is transferred to the fluidized bed tanks. These tanks are re-circulated slowly to allow the continuation of the crystallization process which was initiated in the reactor. The system consists of three identical tanks with their accompanying piping and valves. Any or all three can be used as the situation requires.

SETTLING SYSTEM

The settling system consists of four parallel tanks containing baffles through which the brine containing the precipitates flows. The flow is slow and linear to allow the precipitates to settle. The volume of precipitates (sludge) in the settling tanks are monitored. Depending on the flow rate, the sludge is periodicaly vaccuumed from the tanks to avoid sludge spillover into the filter tanks. The brine can be, and has been treated with a flocculating agent prior to flowing into the settling tanks. To date, this flocculation treatment has been successful and has greatly enhanced the settling of the sludge.

FILTER SYSTEM

The filter system consists of three parallel tanks with approximately four feet of graded filter media. The filter media consists of (in order from the bottom up) (1) 1-1/2" x 3/4" gravel, (2) 3/4" x 3/8" gravel, (3) 3/8" x 1/4" gravel, (4) garnet gravel, (5) fine garnet, (6) sand (.55mm), (7) anthracite. The design of the filter media was done by Neptune Micro-Floc.

Each tank was compartmentized to reduce the pump horsepower required for backwashing. The overall dimensions of the tanks (37 ft long by 7 ft wide) with this particular filter media would require between 8,000 gpm and 10,000 gpm. Thus, by compartmentizing and designing for backwashing one compartment at a time, the required backwash rate (and the required pump horsepower) were considerably reduced. The backwash requirements initially posed considerable problems. A primary problem was where to store the needed backwash fluid. The pumping rate increased considerably with temperature. Thus, using hot brine was not considered efficient. Also, using the brine directly from the settling system would cause considerable operational problems. Therefore, produced brine was stored in a sump. The brine was allowed to cool and then used for backwashing which drastically increased the backwash efficiency.

Each tank can initially handle about 1,000 gpm. Thus, usually one tank at a time can be on stream to handle the flow. One tank can be ready and the third tank can be in the backwash mode. High solids concentration increases the backwash frequency and also reduces the filter throughput capacity. When this occurs two filters can be on stream with one tank in the backwash mode. Oxygen contamination of the brine and subsequent filter plugging problems are critical and can be solved through additions of hydrazine. Over treatment with hydrazine must be avoided, otherwise chemical reactions will lead to different types of plugging problems.

REINJECTION SYSTEM

The reinjection system consists of temporary holding tanks and reinjection pumps. It has been found that two parallel pumping systems each consisting of two pumps in series are necessary. The system must be capable of about 500 psi to 700 psi at the maximum anticipated flow rates (usually no less than 1,500 gpm). Past experience has proven that considerable problems can occur during testing of unknown reservoirs because of inadequate reinjection pump capacities.

HARDWARE AND CONTROLS

Numerous operational problems have been encountered with the hardware and controls because of the produced fluids and solids. Most operating problems are related to the valves. Three types of valves have been used. The slab gate valves are the primary valves used in the system. Vee-ball valves have been used for control. However, any hard scale deposition renders the vee-ball valves inoperative very rapidly. The gate valves can be forced to operate under extreme scaling conditions. Frequent operation of the gate valves to keep the scale to a minor build-up has worked successfully for well testing. Sliding gate valves have also been used. The primary problem with these valves is the difficulty to repair these valves.

Level control in the separators is a major problem because the site glasses scale very quickly. Differential pressure transmitters have worked well. Automatic level control is used on the separators. However, automatic level controllers tend to overact, thus causing detrimental interferences in the test work. The operating personnel have found that under continuous flow at fixed conditions, hand operating the level controls gives much more uniform rate data. This is because the production is not uniform at the surface and momentary changes in liquid rate cause unnecessary readjustment using automatic controllers. In permanent facilities this is not critical. However, during testing very accurate data are required and overacting controllers cause problems regarding the data collection.

Because the physical system is designed to operate under a variety of conditions each unit in the facility must be constantly manned. Trained operating personnel are mandatory in conducting a successful test. The operation of the unit is quite complex and considerable effort is placed into training the personnel. Other than problems with the produced fluids and the equipment, improperly trained personnel can cause the test to be a failure. These failures can be caused either by faulty equipment operations or by the inability to acquire the required data due to improper unit operations. Very well organized well testing is now being conducted due to the concentrated effort on training the personnel.

IN-LINE MONITORING

Most instrumentation used conventionally in geothermal test facilities consists of bourdon tube pressure gauges, bimetallic temperature gauges and orifice flow meters. This type of instrumentation is inadequate for any advanced field test work.

Proper instrumentation and controls are critical for the well test work. Considerable efforts were spent to equip the test facility with a sufficient number of accurate and reliable instruments. All instruments are supplied with a back-up system of gauges and binetallic thermometers. Pressures, temperatures, flow rates, pH, concentrations and conductivities should be measured, respectively, with pressure transducers, tip sensitive RTD's, automatic pH monitors, and specific-ion and conductivity measuring devices. The measured data are collected on mass storage media. These are industry standard and cassette tapes. The data is then transferred to magnetic storage after processing the data through an automatic data logger which is housed in an instrument trailer. The data logger also provides a paper printout for an instant hard copy. The data on the field tapes are later transcribed and formatted onto industry standard magnetic tape which is compatible with the operator's computing system.

The back up instrument system consists of conventional pressure and temperature gauges which require manual reading and recording.

In theory, this automatic data acquisition system should be sufficient for these test operations. Unfortunately, this is not the case in practice. The pressure transducers are prone to clogging with scale and must be cleaned and recalibrated frequently. Some type of transducers (e.g., Sensotec strain gauge pressure transducers) are more prone to clogging than others (e.g., Validyne variable reluctance transducers.) The need for frequent recalibrations and cleaning dictates the use of transducers which can easily be taken apart. Here again, we have had very good experience with the Validyne transducers as opposed to the Sensotec models. The RTD's are subject to loss of calibration (due to vibrations and the harsh environment) and thermowells scale up, thus giving false or misleading temperature data. The orifices in the brine lines scale up, thus generating false rate measurements. The pH meters are not useable at high pressures and temperatures in excess of approximately 230'F.

Summarizing, we can state that conventional in-line monitors (pressure transducers, RTD's, pH elctrodes, orifice plates, etc.) are not adequately designed or applicable for the hostile environment of geothermal fluids. Only frequent and elaborate recalibrations, repairs and internal checking procedures allow the critical data to be collected with a high degree of accuracy and reliability. Both sophisticated temperature and pressure calibration equipment (traceable to NBS standards) became an integral part of the present test facilities.

Additional types of in-line monitors such as ion-specific electrodes and various types of rate meters are desperately needed for the geothermal industry. A separate report on these measuring and monitoring problems will be issued soon under the auspices of DOE/DGE.

SAMPLING AND ANALYSES

Sampling and analyses of all pertinent liquids, gases and solids play a key role in our well test program. All critical properties of the various liquids, gases and solids formed as a function of decreasing pressure and temperature in the flowing geothermal fluids must be known in great detail. Only proper sampling and analyses will allow the determination of many of these critical properties.

As previously presented by Vetter [4,5,6], sampling in geothermal operations can get rather complex. Presently, proper sampling and analyses of the various fluids in geothermal operations are not standardized. Many operators use sampling procedures which will generate misleading analytical data for their field operations. Some of the analytical procedures commonly used are also subject to false data generation. One has to keep in mind that much of the entire investment for the development of a geothermal prospect can easily be placed upon false or misleading information on the critical fluid properties. Therefore, proper sampling and analyses are extremely critical.

The main reason for these frequently observed failures is that the extreme thermodynamic instability of most geothermal fluids is grossly neglected. The flowing fluids within the field installations can have properties which are quite different from samples collected and shipped in a container at ambient temperature and pressure. For example, the steam in a pipeline can be a uniform mixture of various gases at the line temperature, whereas a condensed sample consists of a liquid and a gas phase, both having different properties. Major differences in the critical properties exist not only between the collected liquid and gas samples but between the collected samples and the original steam in the flow line. Even though this may sound rather trivial, these differences in the properties are often neglected in a quite irresponsible manner. In addition, the geothermal fluids may drastically change their properties as they travel within the pipelines from locations of high temperature and pressure to those of low temperature and pressure. Therefore, sampling in one location requires a certain sampling procedure resulting in a set of certain fluid properties, whereas sampling in downstream locations may necessitate a quite different sampling procedure and may result in a quite different set of fluid properties.

SAMPLING EQUIPMENT AND PROCEDURES

Based on many years of experiences in sampling of various geothermal fluids for numerous private and government organizations (Union Oil, RGI, Mapco, MCR, Battelle PNL, etc.), it was decided to use only a limited number of proven and reliable sampling methods. This would normally cause a major problem: quite often, fluid properties are required to be known under conditions for which proven and reliable sampling methods do not exist. Of particular interest are the fluid properties in two-phase systems. In these cases, the critical components of the test unit are operated under conditions which allow us to collect relevant samples. In other words, operating of the test facilities and sampling must go hand in hand.

The hardware used for sampling equipment consist mainly of:

Several hundred sample ports (0.5" collars, nipples and ball valves)

Cooling coils with fine regulating needle valves

Traversing sampling probes with pressure glands

Various types of spargers and absorption equipment

Liquid-gas separators

High and low pressure filtration equipment

Much of this sampling equipment and the sampling procedures is incorporated into Battelle's final report on the subject [7].

CHEMICAL ANALYSES

Reliable and accurate chemical analyses which are required in large numbers provide numerous headaches. Sophisticated and fully automated, computerized instrumentation is required to provide the large number of analytical data and to keep track of all the collected information in a manageable way. The backbone of our analytical intrumentation is a combination of:

1. A 36 channel ICAP (inductively coupled argon plasma spectrometer) and a fully automated titrator for the liquids

2. A specialized gas chromatograph for the gases

3. An SEM operated in various modes coupled with an X-Ray analyzer (microprobe) and an X-Ray diffractometer for the solids.

All instruments are specially set up

and meticulously calibrated for geothermal fluid and solid investigation. Most of the data derived from this advanced and modern analytical instrumentation is collected on magnetic tape or discs for an immediate computerized internal consistency check. Programs had to be developed to provide this rapid and reliable internal check through a "red flag" system. Additional benefits of the computerized data managemment system are the capabilities to evaluate the data using rapid computerized methods and to easily combine the computerized analytical data with the computerized flow data from the field data loggers.

DATA MANAGEMENT

A common problem for geothermal well testing is posed by the usual lack of an efficient data management system. Basically, two types of data will be obtained from a well test (30-day flow test):

1. Pressure, temperature and flow data as measured at the various points in the production test facility.

2. Chemical data from the sample analyses (solids, liquids and gases) obtained in the laboratory.

To manage the high density data is difficult. If the entire job is properly conducted, one will obtain literally several hundred thousand or even millions of data points. It may look like luxury to acquire this much data. However, it is very difficult to predetermine which data are pertinent for the evaluations and which are not. Obviously, it is easier and by far more economical to delete measured excess data than to generate missing data points after the field test work is completed.

The approach we have taken to handle this massive data flux involves the field data acquisition, then the laboratory data acquisition and, finally, the combining of these data through an automatic data evaluation system.

The data logger, mentioned earlier, will allow us to acquire and store all pertinent field data at almost any desired data density. All critical sensors for temperature, pressure and flow are connected to this data logger. The magnetic tapes or cassettes of the logger are transcribed onto any convenient data mass storage medium and can, therefore, easily be transcribed for use by the geothermal operator for further evaluation.

All major labortory equipment data output are also computer based. Thus, the instrument output is also stored on data mass storage medium. For example, all liquid samples collected in the field will be analyzed by ICAP (Inductively Coupled Argon Plasma Spectrometer). The ICAP data are automatically transcribed onto another nine (9) track, industry-standard magnetic tape.

Both the laboratory and field data are easily tied together through their common parameters. One common parameter is the time of measuring the variable of interest in the field and/or the time at collecting the sample at the test site. The second parameter used to tie together laboratory and field data (pressure, temperature and/or rate) is the location within the test facility where data was collected.

The two tapes (laboratory data and field data) can be combined into one tape which is then given to the operator for permanent record keeping.

RECENT EXPERIENCES WITH GEOTHERMAL WELL TESTING

As mentioned above, a number of well tests using the described facilities have been conducted. The original design of the test unit consisted only of a high and low pressure system (Figure 2). The concept of this facility was primarily based upon earlier test experiences at Union Geothermal's Brawley and RGI's East Mesa [8,9] and Westmorland fields. These brines cover a wide range of temperatures and brine compositions. This prevsious test work revealed a wide spectrum of problems to be expected during geothermal well testing.

A portion of the test unit (high pressure section and instrumentation) was used for a pit test at RGI's Fee 1 in Niland, California (seeFigure 5). Even though the high pressure and data management system performed according to our specifications, some problems become obvious:

1. Uncontrolled scale formation can lead to a slow deterioration of the unit performance.

2. The instrumentation needs careful and constant attendance.

3. Even though only a portion of the entire unit was used, the skill and talent to operate the system had to be acquired by the field personnel. This can be a slow process due to the uniqueness of these operations.

After this shake-down at RGI's Fee well, a more complete unit was moved to the Mapco Currier site in Westmorland (see Figure 6). Here a quite different set of problems was encountered:

1. The need for specialized filration equipment tailored to the site-specific requirements became evident.

2. Production of formation sand and drilling fines can play havoc with the brine treating facility.

3. The limitations of some instrumentation became evident.

4. Operating of the brine treatment facilities required more skill and personnel training than anticipated.

Despite these and some more problems [2], the test could be successfully completed. To our own surprise, the brine treating facilities could handle the production of overwhelming large amounts of solids (in excess of 1,000 cubic yards [2]).

Initial corrosion and filter plugging problems were quickly traced to oxygen contaminations. After solving the filter and injection wellbore plugging problems through acidizing, these problems were overcome by hydrazine additions. Even very small amounts of hydrazine scavenge all penetrating oxygen and help to keep the iron content of the brine at the Fe^{++} ion state. The iron ions must be kept at the "two valency" state. This turned out to be a critical requirement for all further test work to avoid filter and injection wellbore plugging problems.

After this Mapco test, the test

facility was installed at MCR's Mercer 2 site. A shut-down was required after 14 days of operation. This shut-down was forced by:

1. Formation of large quantities of a rather exotic scale (iron-oxy-hydroxy-chloride). The most frustrating experience was our inability to operate the valves to control the test unit because of this scale formation.

2. Even though the carry-over in the steam phases was extremely small (separator efficiency in excess of 99.9%), the reactor developed an untolerable amount of salt spray. This was caused by the brine and steam flow patterns within the reactor. After the interim shut-down, the data accumulated so far was evaluated and counter measures were taken. These countermeasures consisted of the addition of a sacrificial test loop (Figure 3). This loop allows the deposition of scale in a preferred location as mentioned earlier. So far, this forced scale deposition seems to work according to the design and specifications. Also, the inlet posts of the reactor vessel were changed to decrease its tendency to form salt spray. A de-Mister was added to retain the remaining droplets of salty brine within the reactor.

PRESENT CONCLUSIONS

The ongoing geothermal well test program proved to be more efficient and economical than previously observed or reported well test programs. The test facilities will allow an operator to evaluate his geothermal prospect:

1. Within a minimum time of 30 days,

2. At a minimum cost with a minimum risk for producing and injection wells.

3. With a maximum density flux of data.

The present design of the test facilities may or may not be final. Due to the extremely large degree of flexibility designed into these test facilities, various processes or problems can be evaluated with this unit. Almost any type of modifications and/or additions can be made because of the applied "building block system". Various components or systems can be added to or deleted from this test unit with minimum efforts. Special geothermal processes related to various brine production, utilization and brine reinjection problems can be easily conducted. This flexibility and the portability are major assets of this test unit. We hope that a large number of additional "building blocks" will be designed and constructed as the need arises. Thus, these "building blocks" become interchangeable shelf-items for a large variety of geothermal well test operations.

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TABLE 1

DESIGN CAPACITY

FOR FLOW TEST FACILITY

MAX. BRINE TEMP:	515°F
MAX. FLOW RATE AT 500°F:	1,000,000 lbs/hr (Total mass)
MAX. FLASH IN HPS:	5% (T=468°F)
MAX. FLASH IN LPS:	29.9% (T=235°F)
MAX. STEAM RATE IN HPS:	50,000lbs/hr (T=468°F)
MAX.STEAM RATE IN LPS:	299,000 lbs/hr (T=235°F)
MAX.BRINE RATES IN HPS:	1,000.000 lbs/hr (645 psig)
MAX BRINE RATE IN LPS:	746,000 lbs/hr (T=285°F, 40 psig)

Figure 1

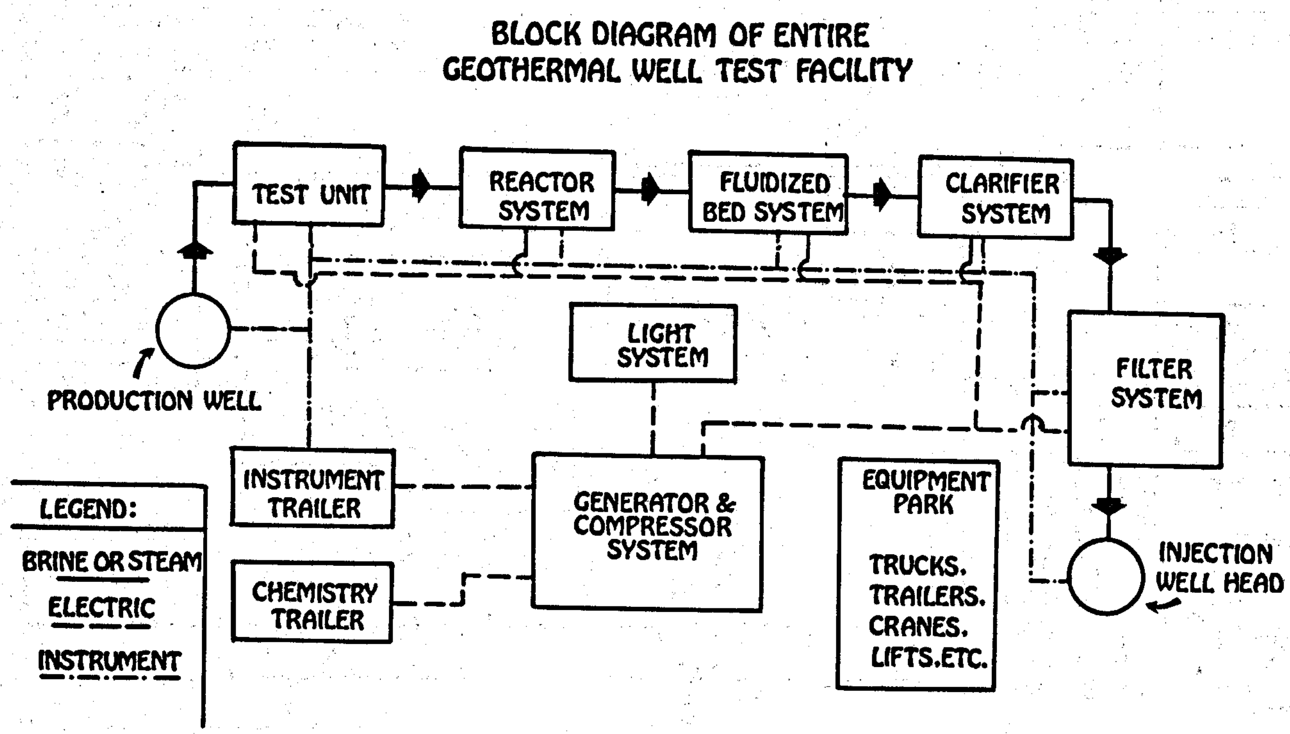
BLOCK DIAGRAM OF ENTIRE
GEOTHERMAL WELL TEST FACILITY
TEST UNIT
REACTOR SYSTEM
FLUIDIZED BED SYSTEM
CLARIFIER SYSTEM
PRODUCTION WELL
LIGHT SYSTEM
FILTER SYSTEM
INSTRUMENT TRAILER
GENERATOR & COMPRESSOR SYSTEM
EQUIPMENT PARK
TRUCKS. TRAILERS. CRANES. LIFTS.ETC.
CHEMISTRY TRAILER
INJECTION WELL HEAD
LEGEND:
BRINE OR STEAM
ELECTRIC
INSTRUMENT

Figure 2

EQUIPMENT LAYOUT FOR THE MCR MERCER 2

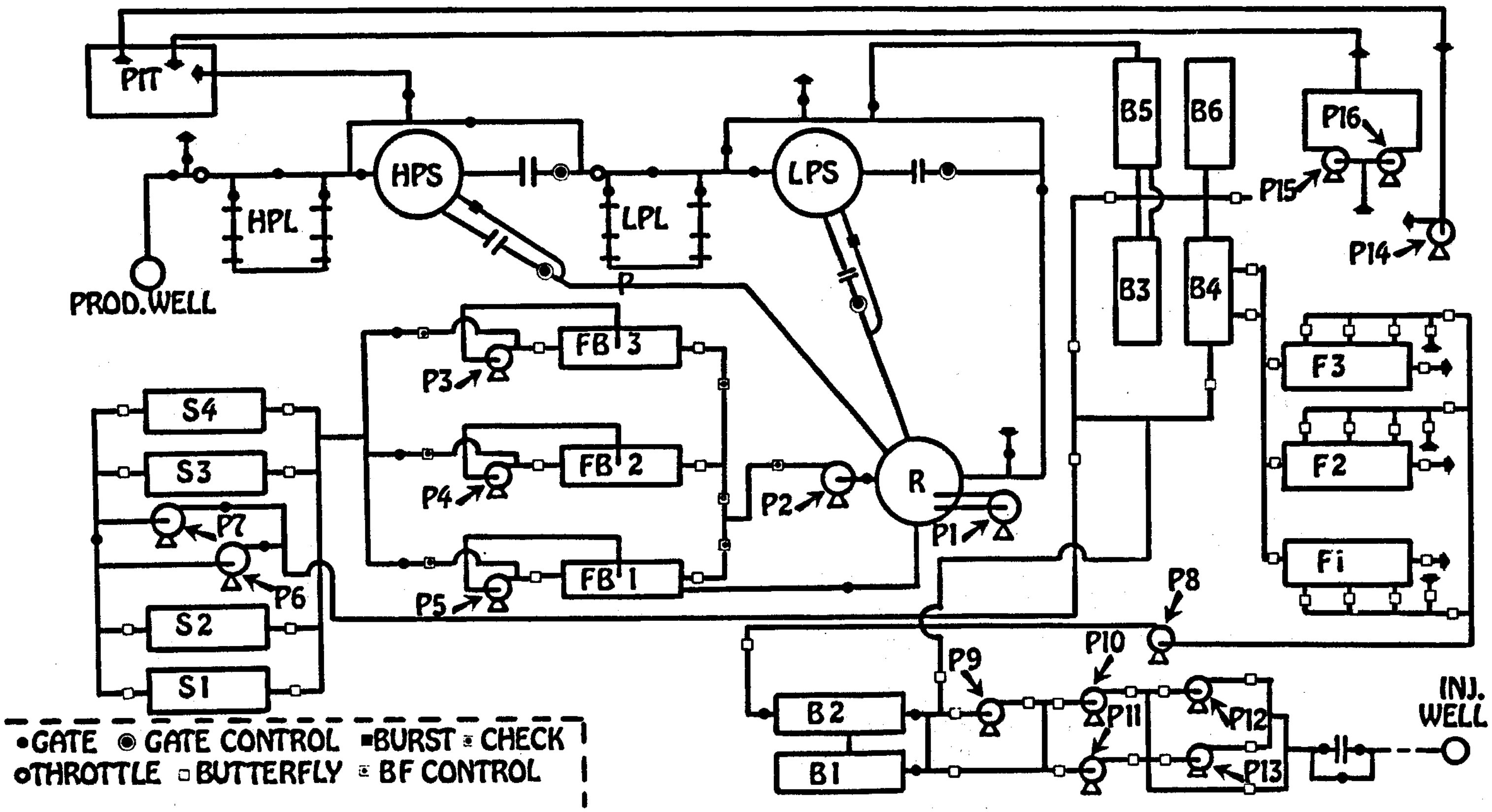

Figure 3

EQUIPMENT LAYOUT FOR SACRIFICIAL SPOOLS
FOR SCALE REMOVAL AT MCR's MERCER 2 WELL

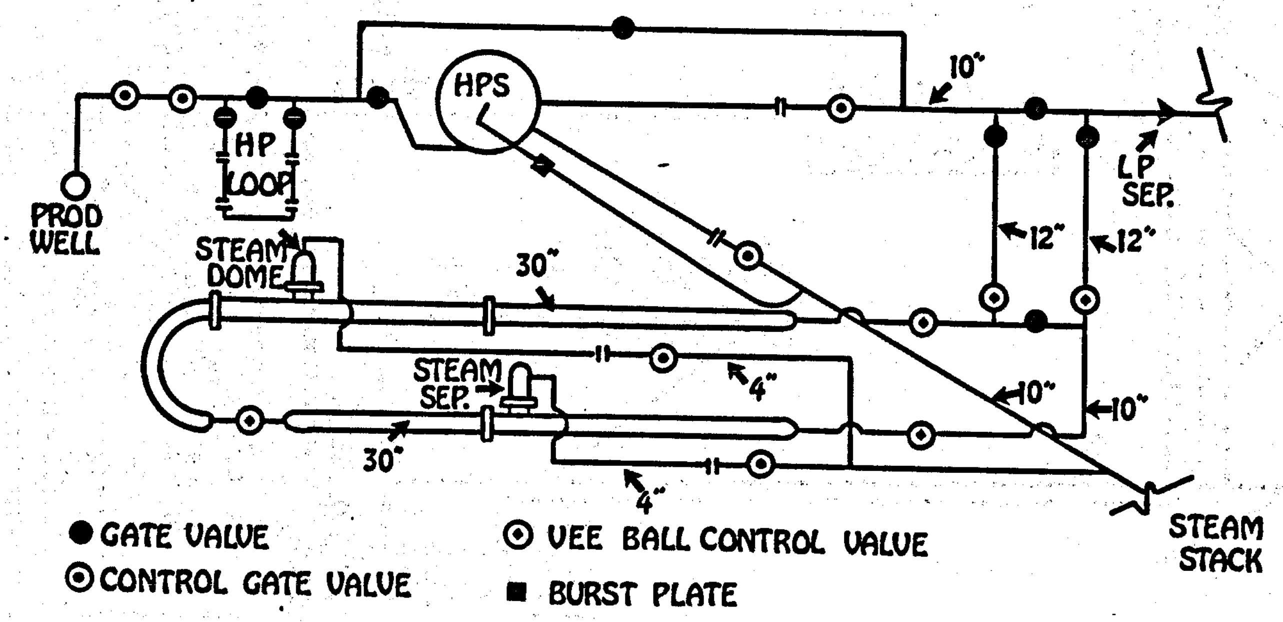

Figure 4

REACTOR VESSEL

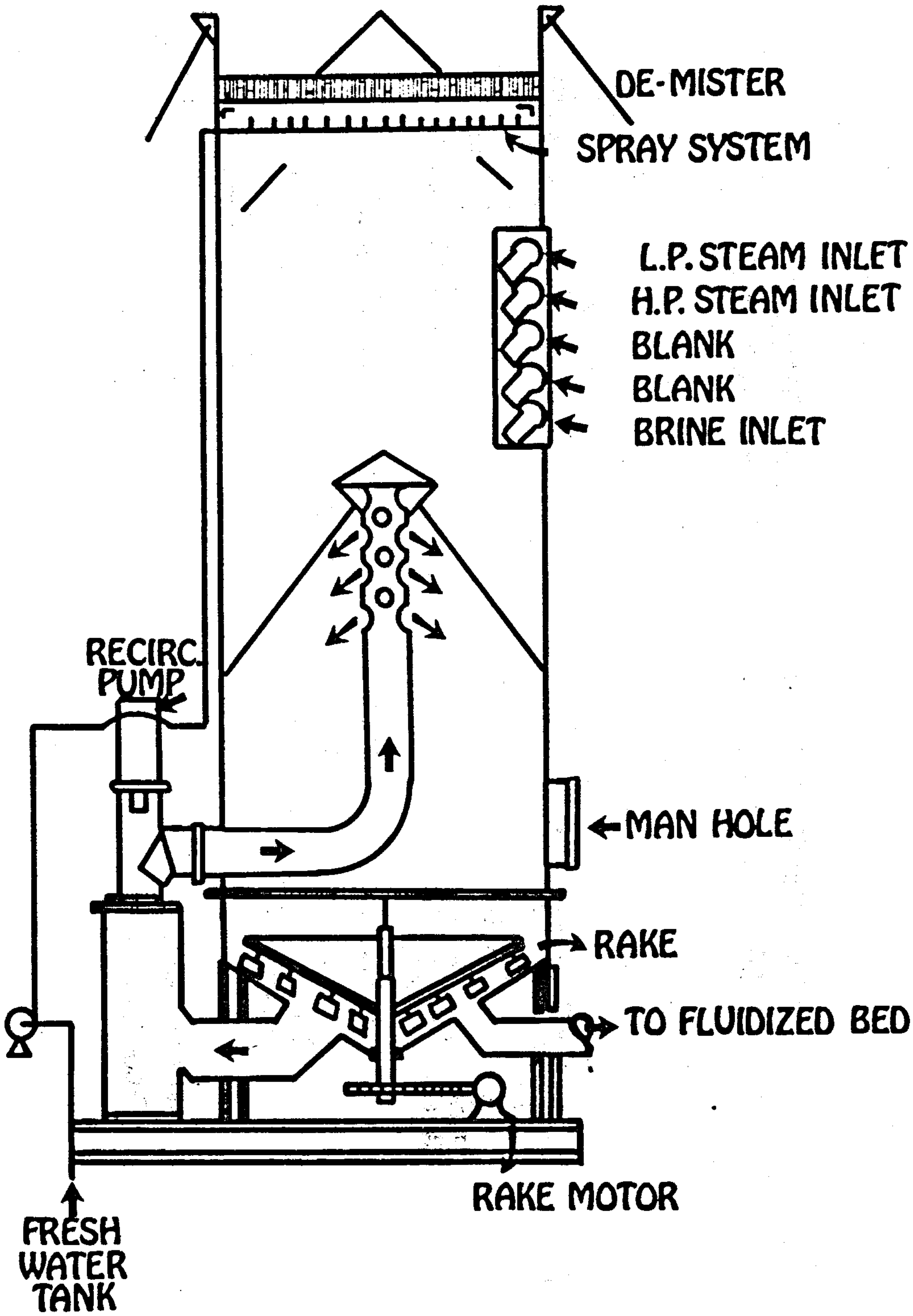

Figure 5

DATA LOGGER MONITORING POSITIONS FOR RGI'S FEE NO. 1 WELL TEST (APRIL 22-APRIL 27, 1980)

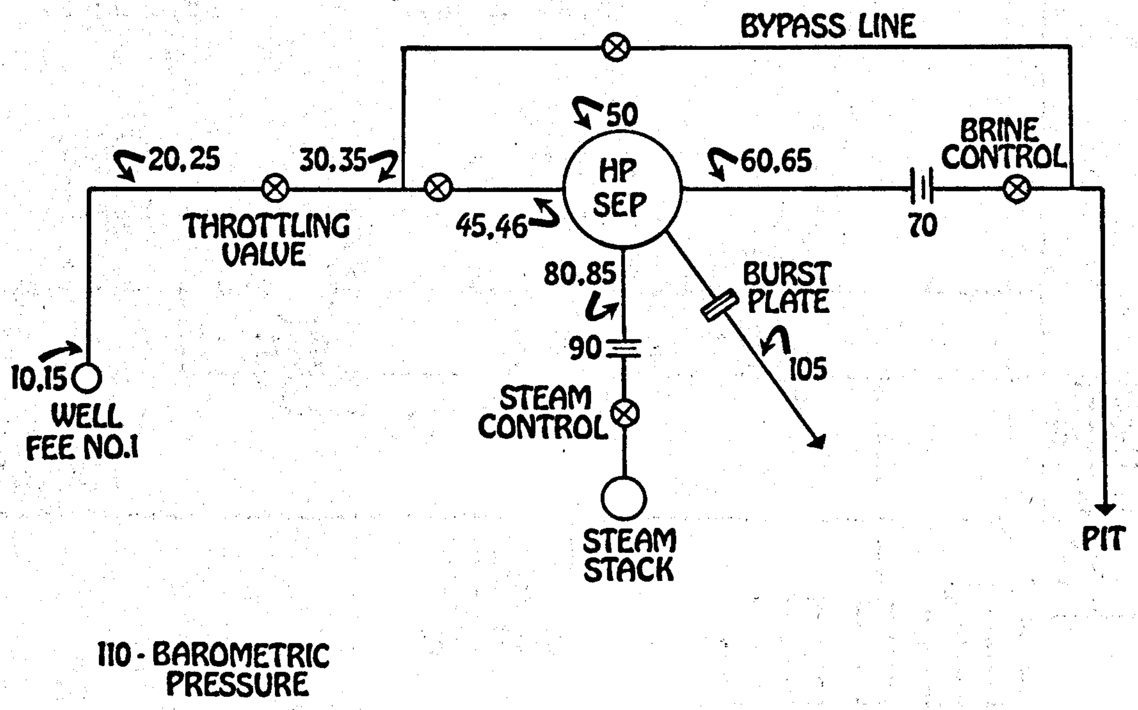

Figure 6

EQUIPMENT LAYOUT FOR THE MAPCO CURRIER 2 30 DAY WELL TEST (JUNE 3,1980 - JULY 3,1980)